

Resonance catalyzed CP asymmetries in $D \rightarrow P\ell^+\ell^-$

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Recently observed increase of direct CP asymmetry in charm meson nonleptonic decays is difficult to explain within the SM. If this effect is induced by new physics, this might be investigated in other charm processes. We propose to investigate new CP violating effects in rare decays $D \rightarrow P\ell^+\ell^-$, which arise due to the interference of resonant part of the long distance contribution and the new physics affected short distance contribution. Performing a model independent analysis, we identify as appropriate observables the differential direct CP asymmetry and partial decay width CP asymmetry. We find that in the most promising decays $D^+ \rightarrow \pi^+\ell^+\ell^-$ and $D_s^+ \rightarrow K^+\ell^+\ell^-$ the “peak-symmetric” and “peak-antisymmetric” CP asymmetries are strong phase dependent and can be of the order 1 % and 10 %, respectively.

PACS numbers: 13.20.Fc, 11.30.Er

I. INTRODUCTION

In last two decades chances to observe new physics in charm processes were considered to be very small. In the case of flavor changing neutral current processes the Glashow-Iliopoulos-Maiani (GIM) mechanism plays a significant role, leading to cancellations of contributions of s and d quarks, while intermediate b quark contribution is suppressed by V_{ub} element of the Cabibbo-Kobayashi-Maskawa (CKM) matrix. The lack of appropriate theoretical tools to handle long distance dynamics in these processes is even more pronounced than in the case of B mesons due to abundance of charmless resonances with the masses close to the masses of charm mesons. However, this has changed at the end of last year when LHCb experiment reported a non-vanishing direct CP asymmetry in $D^0 \rightarrow K^+K^-$ and $D^0 \rightarrow \pi^+\pi^-$ [1] also confirmed by the CDF experiment [2]. Many papers investigated whether this result can be accommodated within the standard model (SM) or is it new physics (NP) that causes such an effect. The measured difference between the CP asymmetry in $D^0 \rightarrow K^+K^-$ and $D^0 \rightarrow \pi^+\pi^-$ is a factor 5 – 10 larger than expected in the SM and eventually can be a result of nonperturbative QCD dynamics as pointed out in refs. [3–10]. Model independent studies [11, 12] indicated that among operators describing NP effect, the most likely candidate is the effective $\Delta C = 1$ chromomagnetic dipole operator. In order to distinguish between SM or NP scenarios as explanation of the observed phenomena it is crucial to investigate experimentally and theoretically all possible processes in which the same operator might contribute. Recently the effects of the same kind of new physics have been explored in radiative [13] and inclusive charm decays with a lepton pair in the final state [14]. In [13] it was found that NP induces an enhancement of the matrix elements of the electromagnetic dipole operators leading to CP asymmetries of the order of few percent.

In addition to radiative weak decays, charm meson decays to a light meson and leptonic pair might serve as a testing ground for CP violating new physics contributions. As in other weak decays of charm mesons the long distance dynamics dominates the decay widths of $D \rightarrow P\ell^+\ell^-$ [15–17] and it requires special task to find the appropriate variables containing mainly short-distance contributions. In this study we investigate partial decay width CP asymmetry in the case of $D \rightarrow P\ell^+\ell^-$ decay. The short distance dynamics is described by effective operators \mathcal{O}_7 , \mathcal{O}_9 , and \mathcal{O}_{10} of which the electromagnetic dipole operator \mathcal{O}_7 carries a CP odd phase of beyond the SM origin, developed due to mixing under QCD renormalization with the chromomagnetic operator. In this paper we investigate impact of this mixing on the $D \rightarrow P\ell^+\ell^-$ decay dynamics. The paper is organized as follows: Section II contains the description of the short distance contributions, Sec. III is devoted to the long distance dynamics. In Sec. IV we present the partial width asymmetry. We summarize our findings in Sec. V.

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II. CP-ODD EFFECTIVE HAMILTONIAN

The genuine short distance (SD) dynamics of $c \rightarrow u\ell^+\ell^-$ decay on scale $\sim m_c$ is defined by the effective Hamiltonian

$$\begin{aligned}\mathcal{H}_{\text{eff}} &= \frac{-4G_F}{\sqrt{2}} \sum_{i=7,9,10} \mathcal{O}_i, \\ \mathcal{O}_7 &= \frac{em_c}{(4\pi)^2} \bar{u}\sigma_{\mu\nu}P_R c F^{\mu\nu}, \\ \mathcal{O}_9 &= \frac{e^2}{(4\pi)^2} (\bar{u}\gamma^\mu P_L c)(\bar{\ell}\gamma_\mu \ell), \\ \mathcal{O}_{10} &= \frac{e^2}{(4\pi)^2} (\bar{u}\gamma^\mu P_L c)(\bar{\ell}\gamma_\mu \gamma_5 \ell).\end{aligned}\tag{1}$$

SD amplitude has contributions from electromagnetic penguin \mathcal{O}_7 and four-fermion operators with vector and axial lepton current, \mathcal{O}_9 and \mathcal{O}_{10} , respectively, and while their contribution to the decay width is negligible in the resonance-dominated regions, possible imaginary parts of Wilson coefficients may generate direct CP violation via interference with the CP-even long distance amplitude. Here we will assume that $C_7(m_c)$ has a large NP phase. It can be naturally induced by QCD mixing between C_7 and C_8 and an assumption that direct CP in singly Cabibbo suppressed decays is explained by new physics in C_8 . We consider the range proposed in [13],

$$|\text{Im } C_7(m_c)| = (0.2 - 0.8) \times 10^{-2}.\tag{2}$$

Unlike in the B meson decays, contributions of the third generation quarks in the flavor changing neutral current loops are not favored over the first and second generation quarks in charm decays. Effects of virtual light quarks cannot be expanded in series of local operators as in (1) since they are genuine long-distance (LD) effects and we will address them in the next section. Keeping only the CP-violating part of the SD amplitude of $D \rightarrow \pi\ell^+\ell^-$, where $\ell = e, \mu$, we have

$$\mathcal{A}_{\text{SD}}^{\text{CPV}} = -\frac{i\sqrt{2}G_F\alpha}{\pi} C_7(m_c) \frac{m_c}{m_D + m_\pi} f_T(q^2) (\bar{\ell}\not{p}\ell),\tag{3}$$

where p is momentum of the D meson. The form factors for $D \rightarrow \pi$ transition via vector current and electromagnetic dipole operators are defined as customary

$$\begin{aligned}\langle \pi(p') | \bar{u}\gamma_\mu c | D(p) \rangle &= \left[(p + p')_\mu - \frac{m_D^2 - m_\pi^2}{q^2} q_\mu \right] F_1(q^2) + \frac{m_D^2 - m_\pi^2}{q^2} q_\mu F_0(q^2), \\ \langle \pi(p') | \bar{u}\sigma_{\mu\nu} c | D(p) \rangle &= -i (p_\mu p'_\nu - p_\nu p'_\mu) \frac{2f_T(q^2)}{m_D + m_\pi},\end{aligned}\tag{4}$$

with $q^2 = (p - p')^2$. In the heavy quark limit of large m_c the matrix elements of tensor and vector operators are related in the rest-frame of the heavy meson [18]

$$\langle \pi(p') | \bar{u}\sigma_{i0} c | D(\mathbf{0}) \rangle = i \langle \pi(p') | \bar{u}\gamma_i c | D(\mathbf{0}) \rangle.\tag{5}$$

The form factor f_T is then connected to F_1 and F_0 [19]

$$2f_T(q^2) \frac{m_D}{m_D + m_\pi} = F_1(q^2) \left(1 + \frac{m_D^2 - m_\pi^2}{q^2} \right) - F_0(q^2) \frac{m_D^2 - m_\pi^2}{q^2}.\tag{6}$$

Close to the kinematical point of pion at rest, $q^2 \approx m_D^2$, the form factors scale as $F_1/F_0 \sim m_D$ [18, 20] and the above relation reduces to $f_T \approx F_1$. Form factors $F_{1,0}(q^2)$ for $D \rightarrow \pi$ transitions have been computed in unquenched lattice QCD simulation with staggered light quarks in ref. [21]. There the shapes of the form factors are presented in the Bećirević-Kaidalov

parameterization [22],

$$F_1(q^2) = \frac{F_1(0)}{\left(1 - \frac{q^2}{m_{D^*}^2}\right) \left(1 - a \frac{q^2}{m_{D^*}^2}\right)}, \quad (7)$$

$$F_0(q^2) = \frac{F_1(0)}{1 - \frac{1}{b} \frac{q^2}{m_{D^*}^2}},$$

$$\begin{aligned} F_1(0) &= 0.64(3), \\ a &= 0.44(4), \\ b &= 1.41(6). \end{aligned} \quad (8)$$

We employ the form factor $f_T(q^2)$ as given by heavy quark symmetry relation (6) used with shapes (7), (8) for $F_1(q^2)$ and $F_0(q^2)$.

III. RESONANT AMPLITUDE

The ϕ resonant peak in the lepton invariant mass distribution of $D \rightarrow P \ell^+ \ell^-$ is very narrow ($\Gamma_\phi/m_\phi \approx 4 \times 10^{-3}$) and well separated from other vector resonances. Therefore, close to the ϕ peak the long distance amplitude is, to a good approximation, well dominated by a Breit-Wigner amplitude [15–17]

$$\mathcal{A}_{\text{LD}}^\phi [D \rightarrow \pi \phi \rightarrow \pi \ell^- \ell^+] = \frac{iG_F}{\sqrt{2}} V_{cs}^* V_{us} \frac{8\pi\alpha}{3} a_\phi e^{i\delta_\phi} \frac{m_\phi \Gamma_\phi}{q^2 - m_\phi^2 + im_\phi \Gamma_\phi} \bar{u}(k_-) \not{p} v(k_+). \quad (9)$$

Here we use $\alpha = 1/137$ in the leading order in electromagnetic interaction. Finite width of the resonance generates a q^2 -dependent strong phase that varies across the peak. We have also introduced the strong phase on peak, δ_ϕ , and the normalization, a_ϕ , that are both assumed to be independent of q^2 . Parameter a_ϕ is real and can be fixed from measured branching fractions of $D \rightarrow \pi \phi$ and $\phi \rightarrow \ell^+ \ell^-$ decays [17]. For definiteness we will focus on the $\ell = \mu$ decay modes. From the Particle Data Group compilation we read [23]

$$\begin{aligned} \text{Br}(D^+ \rightarrow \phi \pi^+) &= (2.65 \pm 0.09) \times 10^{-3}, \\ \text{Br}(\phi \rightarrow \mu^+ \mu^-) &= (0.287 \pm 0.019) \times 10^{-3}, \end{aligned} \quad (10)$$

and when we take into account the small width of ϕ

$$\text{Br}(D^+ \rightarrow \pi^+ \phi (\rightarrow \mu^+ \mu^-)) \approx \text{Br}(D^+ \rightarrow \phi \pi^+) \times \text{Br}(\phi \rightarrow \mu^+ \mu^-), \quad (11)$$

we find from eq. (9)

$$a_\phi = 1.23 \pm 0.05. \quad (12)$$

IV. DIRECT CP ASYMMETRY

The direct CP violation in the resonant region is driven by the interference between the CP-odd imaginary part of the SD amplitude and the LD amplitude. The pair of CP-conjugated amplitudes read

$$\begin{aligned} \mathcal{A}(D^+ \rightarrow \pi^+ \ell^+ \ell^-) &= \mathcal{A}_{\text{LD}}^\phi + \mathcal{A}_{\text{SD}}^{\text{CPV}}, \\ \bar{\mathcal{A}}(D^- \rightarrow \pi^- \ell^+ \ell^-) &= \mathcal{A}_{\text{LD}}^\phi + \bar{\mathcal{A}}_{\text{SD}}^{\text{CPV}}. \end{aligned} \quad (13)$$

In principle the short-distance amplitude contains a strong phase that can be rotated away because the overall phase of the total amplitude is irrelevant. The CP-odd part of the LD amplitude is proportional to the imaginary part of the relevant CKM factor

$$V_{cs}^* V_{us} = \lambda + iA^2 \eta \lambda^5, \quad (14)$$

and can be safely neglected and accordingly we have $\mathcal{A}_{LD}^\phi = \bar{\mathcal{A}}_{LD}^\phi$. Then the differential direct CP violation reads

$$a_{CP}(\sqrt{q^2}) \equiv \frac{|\mathcal{A}|^2 - |\bar{\mathcal{A}}|^2}{|\mathcal{A}|^2 + |\bar{\mathcal{A}}|^2} = \frac{-3}{2\pi^2} \frac{f_T(q^2)}{a_\phi} \frac{m_c}{m_D + m_\pi} \frac{\text{Im}C_7}{\text{Re}[V_{cs}^* V_{us}]} \left[\cos \delta_\phi - \frac{q^2 - m_\phi^2}{m_\phi \Gamma_\phi} \sin \delta_\phi \right]. \quad (15)$$

When considering numerics in what follows we will set $\text{Im}C_7$ to the largest possible value of 0.8×10^{-2} for the sake of illustration. Relative importance of the $\cos \delta_\phi$ and $\sin \delta_\phi$ for representative choices of δ_ϕ is shown on the upper plot in fig. 1. The linearly rising behaviour of the $\sin \delta_\phi$ -driven term of the asymmetry is compensated by a rapid drop of the resonant amplitude (9) that severely diminishes number of experimental events as we move several Γ_ϕ away from $m_{\ell\ell} = m_\phi$. Both effects are included in the effective experimental sensitivity that also takes into account the rate of events in the considered kinematical region and is shown on the bottom plot of fig. 1. There we plot $a_{CP}(m_{\ell\ell})$, weighted by the differential branching ratio, a combined quantity that scales as $\sim \mathcal{A}_{LD}^\phi \text{Im}\mathcal{A}_{SD}^{\text{CPV}}$. These sensitivity curves expose entirely different behaviour than $a_{CP}(m_{\ell\ell})$. If the phase δ_ϕ is close to 0 or π one finds the best sensitivity close to the peak. On the contrary, for $\delta_\phi \sim \pm\pi/2$, the CP asymmetry is an odd-function with respect to the resonant peak position and is maximal when we are slightly off the peak. Therefore, experiment collecting events in a symmetric bin around $m_{\ell\ell} = m_\phi$ would be unable to observe CP asymmetry for maximal phase $\delta \sim \pm\pi/2$.

A. Partial-width CP asymmetries

In order to keep the experimental search as general as possible one should use appropriate search strategies to address the two limiting possibilities, i.e. $\delta_\phi = 0, \pi$ and $\delta_\phi = \pm\pi/2$. First, let us define a CP asymmetry of a partial width in the range $m_1 < m_{\ell\ell} < m_2$,

$$A_{CP}(m_1, m_2) = \frac{\Gamma(m_1 < m_{\ell\ell} < m_2) - \bar{\Gamma}(m_1 < m_{\ell\ell} < m_2)}{\Gamma(m_1 < m_{\ell\ell} < m_2) + \bar{\Gamma}(m_1 < m_{\ell\ell} < m_2)}, \quad (16)$$

where Γ and $\bar{\Gamma}$ denote partial decay widths of D^+ and D^- decays, respectively, to $\pi^\pm \mu^+ \mu^-$. A_{CP} is related to the differential asymmetry $a_{CP}(\sqrt{q^2})$ as

$$A_{CP}(m_1, m_2) = \frac{\int_{m_1^2}^{m_2^2} dq^2 R(q^2) a_{CP}(\sqrt{q^2})}{\int_{q_{\min}^2}^{q_{\max}^2} dq^2 R(q^2)}, \quad (17)$$

where

$$R(q^2) = \frac{1}{(q^2 - m_\phi^2)^2 + m_\phi^2 \Gamma_\phi^2} \int_{s_{\min}(q^2)}^{s_{\max}(q^2)} ds \sum_{s_+, s_-} \left| \bar{u}^{(s_-)}(k_-) \not{p} v^{(s_+)}(k_+) \right|^2 \quad (18)$$

involves the resonant shape and the integral of the lepton trace over the Dalitz variable $s \equiv (p' + k_-)^2$ whose kinematical limits read

$$s_{\max/\min}(q^2) = \frac{(m_D^2 - m_\pi^2)^2}{4q^2} - \frac{\left(q^2 \sqrt{1 - \frac{4m_\mu^2}{q^2}} \mp \lambda^{1/2}(q^2, m_D^2, m_\pi^2) \right)^2}{4q^2}, \quad (19)$$

$$\lambda(x, y, z) = (x + y + z)^2 - 4(xy + yz + zx).$$

The $D^+ \rightarrow \pi^+ e^+ e^-$ decay mode been searched for by the CLEO experiment [24] where signal in a bin around the ϕ resonance was observed. The following partial branching ratio was reported

$$\text{Br}(D^+ \rightarrow \pi^+ e^+ e^-)_{|m_{ee} - m_\phi| \leq 20 \text{ MeV}} = (1.7 \pm 1.4 \pm 0.1) \times 10^{-6}, \quad (20)$$

in a bin up covering the region $\sim 5 \Gamma_\phi$ to the left and right from the nominal position of the ϕ resonance. We define the asymmetry on same bin for the $\pi^+ \mu^+ \mu^-$ final state as

$$C_{CP}^\phi \equiv A_{CP}(m_\phi - 20 \text{ MeV}, m_\phi + 20 \text{ MeV}). \quad (21)$$

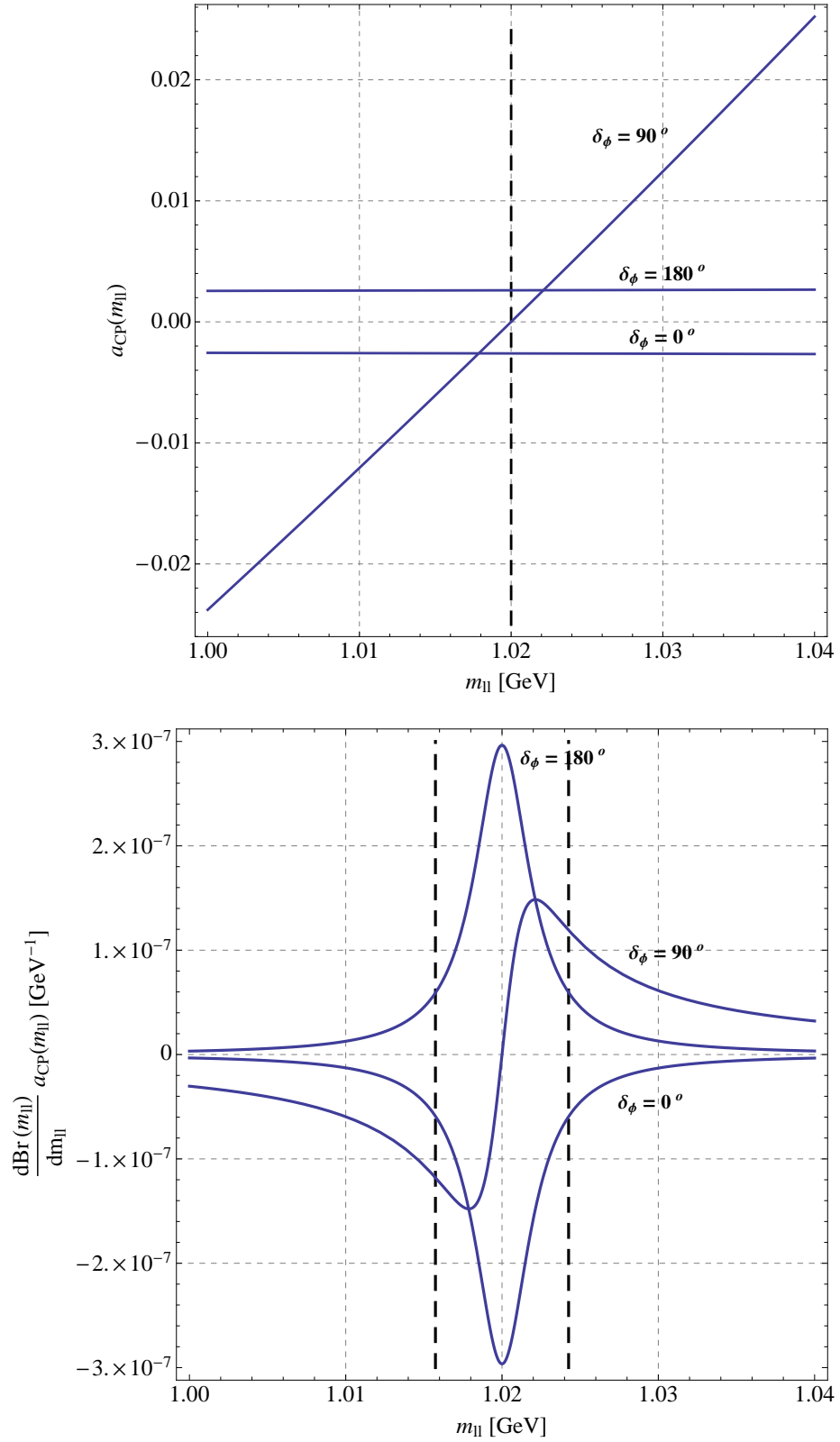


FIG. 1. Top: CP asymmetry $a_{\text{CP}}(m_{\ell\ell})$ around the ϕ resonance (dashed vertical line) for representative values of strong phase $\delta_\phi = 0, \pi/2, \pi$. Bottom: $(d\text{Br}/dm_{\ell\ell}) a_{\text{CP}}(m_{\ell\ell})$, the measure of sensitivity to direct CP-violation. Dashed vertical lines at $m_{\ell\ell} = m_\phi \pm \Gamma_\phi$ denote the width of the resonance.

The asymmetry C_{CP}^ϕ is most sensitive to the $\cos \delta_\phi$ term in Eq. (15) and is therefore optimized for cases when $\delta_\phi \sim 0$ or $\delta_\phi \sim \pi$. Its sensitivity would decrease if we approached $\delta_\phi \sim \pm\pi/2$, since the $a_{CP}(m_{\ell\ell})$ would be asymmetric in $(m_{\ell\ell} - m_\phi)$ in this case. For that very region of δ_ϕ we find the following observable with good sensitivity to direct CP violation

$$S_{CP}^\phi \equiv A_{CP}(m_\phi - 40 \text{ MeV}, m_\phi - 20 \text{ MeV}) - A_{CP}(m_\phi + 20 \text{ MeV}, m_\phi + 40 \text{ MeV}) \quad (22)$$

The bins where the partial width CP asymmetries C_{CP}^ϕ and S_{CP}^ϕ are defined are shown in fig. 2 together with $a_{CP}(m_{\ell\ell})$.

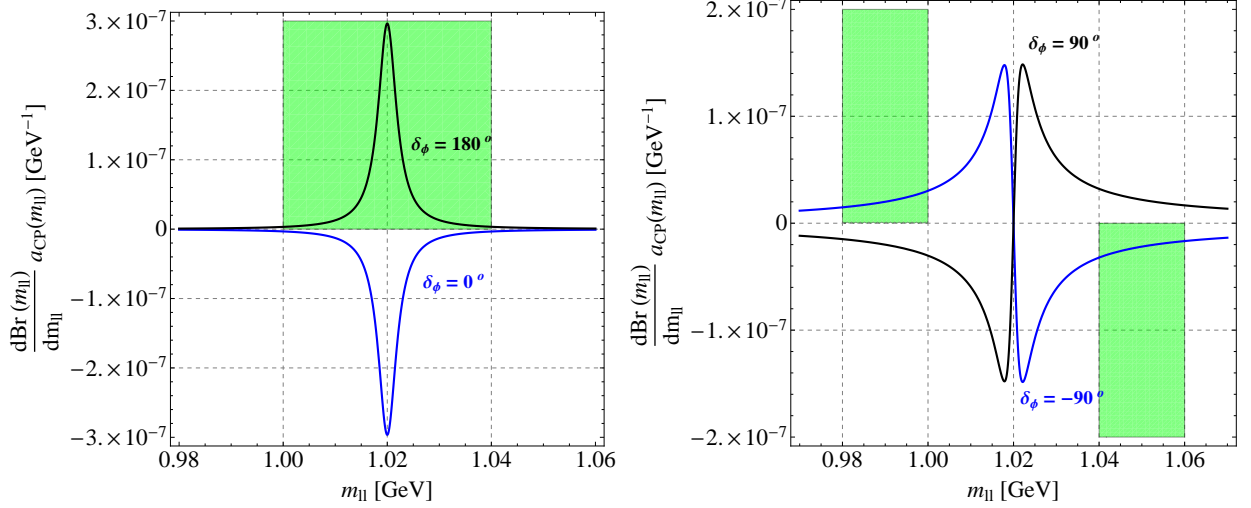


FIG. 2. Left: Asymmetry $a_{CP}(m_{\ell\ell})$ weighted by $d\text{Br}/dm_{\ell\ell}$ in the case when dominated by $\cos \delta_\phi$ term. The shaded region denotes the defining bin for asymmetry C_{CP}^ϕ . Right: $a_{CP}(m_{\ell\ell})$ when dominated by $\sin \delta_\phi$. Shown are also the two bins where the asymmetry S_{CP}^ϕ is defined as the difference of A_{CP} in the two bins.

B. Case study for C_{CP}^ϕ and S_{CP}^ϕ

The asymmetry S_{CP}^ϕ can be an order of magnitude bigger than C_{CP}^ϕ (see fig. 3, left). However, when we rescale the asymmetries by the branching ratios in the bins where these asymmetries defined, namely by 7.1×10^{-7} for C_{CP}^ϕ and 6.7×10^{-8} for S_{CP}^ϕ , we find evenly distributed sensitivity to direct CP violation over entire range of δ_ϕ . Also in the transient regions between the regimes where either $\cos \delta_\phi$ or $\sin \delta_\phi$ terms dominate the sensitivity does not decrease significantly. Numerical values of the central values are summarized in tab. I, whereas the errors coming dominantly from parameter a_ϕ (12) and the form factor f_T (6), (8) are estimated to be of the order 20 %.

δ_ϕ	$C_{CP}^\phi \times 10^2$	$S_{CP}^\phi \times 10^2$	$\text{Br}(\text{C-bin}) C_{CP}^\phi \times 10^7$	$\text{Br}(\text{S-bin}) S_{CP}^\phi \times 10^7$
$0, \pi$	∓ 0.26	± 0.014	∓ 0.018	$\pm 4 \times 10^{-5}$
$\pm\pi/2$	± 0.005	∓ 6.8	$\pm 4 \times 10^{-4}$	∓ 0.017

TABLE I. Values of $D \rightarrow \pi^+ \mu^+ \mu^-$ CP asymmetries C_{CP}^ϕ and S_{CP}^ϕ for representative values of δ_ϕ . Last two columns show effective sensitivity.

C. Comment on $D_s \rightarrow \phi K^+ \rightarrow K^+ \ell^+ \ell^-$

Same type of asymmetries can be defined for the decay mode of D_s meson via the ϕ resonance to final state $K^+ \ell^+ \ell^-$. The resonant amplitude is described by an analogous expression to (9) and is parameterized by real a'_ϕ and δ'_ϕ . The branching ratio

$$\text{Br}(D_s \rightarrow \phi K^+) = (1.8 \pm 0.4) \times 10^{-4}, \quad (23)$$

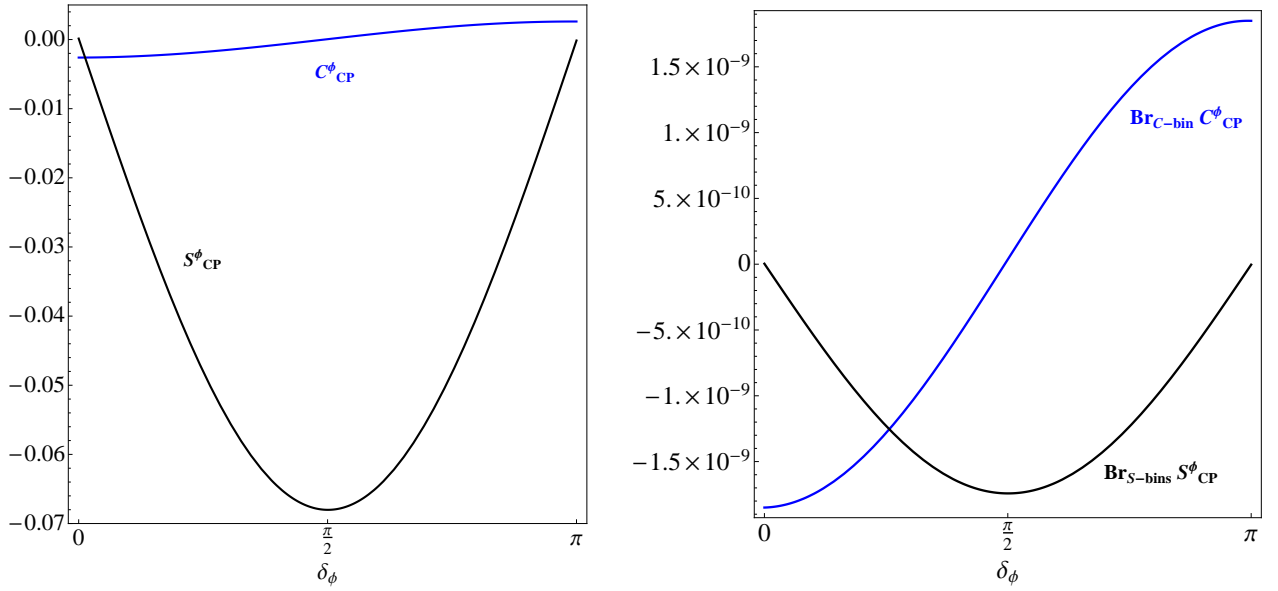


FIG. 3. Partial width asymmetries of $D \rightarrow \pi^+ \ell^+ \ell^-$ decay. Left: asymmetries C_{CP}^{ϕ} and S_{CP}^{ϕ} for $\text{Im}C_7 = 0.8 \times 10^{-2}$ and their dependence on δ_{ϕ} . Right: asymmetries rescaled by the branching ratios in the corresponding bins, thus representing effective sensitivity to direct CP violation.

is an order of magnitude smaller than the corresponding $\text{Br}(D^+ \rightarrow \phi \pi^+)$. By employing the narrow width approximation the value we find $a'_{\phi} = 0.49$ with $\sim 10\%$ error. On the other hand, the short distance amplitude remains of same order of magnitude as in the $D^+ \rightarrow \pi^+ \mu^+ \mu^-$ case. We neglect the $SU(3)$ -breaking corrections to the form factor and use $f_T(q^2)$ as given in (6) adjusted by $m_{\pi} \rightarrow m_K$. The asymmetries $C_{CP}^{\phi'}$ and $S_{CP}^{\phi'}$ are larger, whereas the experimental sensitivity is weaker due to smaller

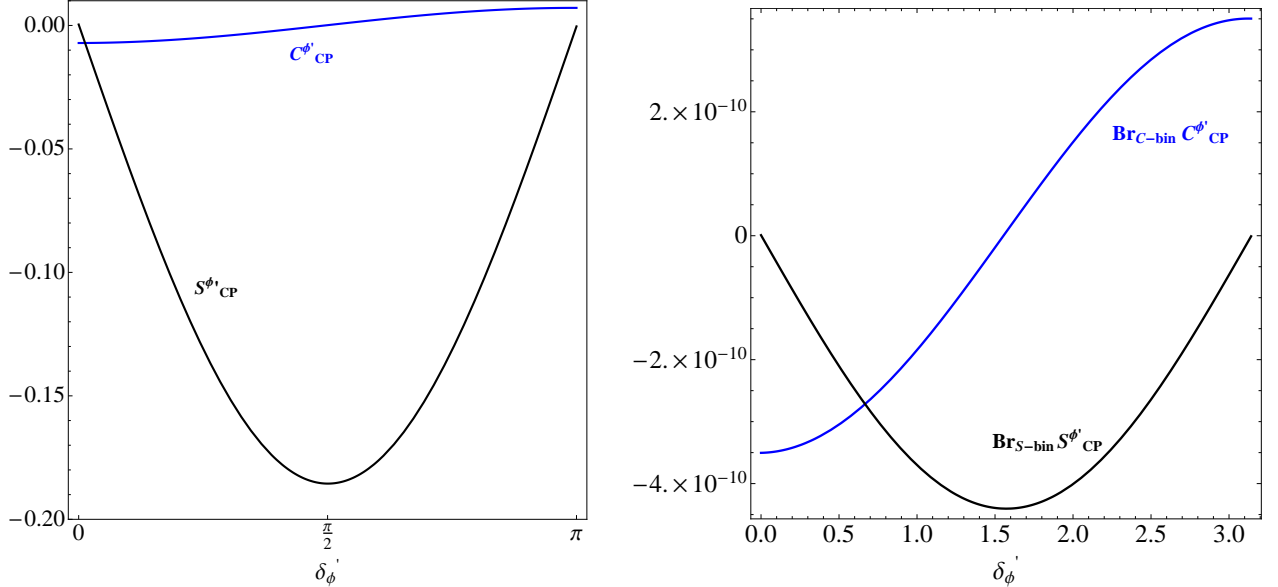


FIG. 4. Partial width asymmetries of $D_s \rightarrow K^+ \ell^+ \ell^-$ decay. Left: asymmetries $C_{CP}^{\phi'}$ and $S_{CP}^{\phi'}$ for $\text{Im}C_7 = 0.8 \times 10^{-2}$ and their dependence on δ_{ϕ}' . Right: asymmetries rescaled by the branching ratios in the corresponding bins, thus representing effective sensitivity to direct CP violation.

branching fractions, as shown in tab. II.

δ'_ϕ	$C_{\text{CP}}^{\phi'} \times 10^2$	$S_{\text{CP}}^{\phi'} \times 10^2$	Br(C-bin) $C_{\text{CP}}^{\phi'} \times 10^7$	Br(S-bin) $S_{\text{CP}}^{\phi'} \times 10^7$
$0, \pi$	∓ 0.71	± 0.038	∓ 0.0035	$\pm 2 \times 10^{-5}$
$\pm \pi/2$	± 0.012	∓ 19	$\pm 6 \times 10^{-5}$	∓ 0.009

TABLE II. Values of $D_s \rightarrow K^+ \mu^+ \mu^-$ CP asymmetries $C_{\text{CP}}^{\phi'}$ and $S_{\text{CP}}^{\phi'}$ for representative values of δ'_ϕ . Last two columns show effective sensitivity.

V. SUMMARY

In this article we have studied CP asymmetries of rare decays $D^+ \rightarrow \pi^+ \mu^+ \mu^-$ and $D_s \rightarrow K^+ \mu^+ \mu^-$ defined close to the ϕ resonance that couples to the lepton pair. These asymmetries can be generated by imaginary parts of Wilson coefficients in the effective Hamiltonian for $c \rightarrow u \ell^+ \ell^-$ processes. We have limited the discussion to the electromagnetic dipole coefficient C_7 which can carry a large CP odd imaginary part, if the direct CP violation in singly Cabibbo suppressed decays $D \rightarrow PP$ is to be explained by NP contribution to the chromomagnetic operator C_8 .

We have focused on the CP asymmetry around the ϕ resonant peak in spectrum of dilepton invariant mass. There approximate description of the resonant amplitude by means of the Breit-Wigner ansatz with two additional parameters seems valid. We have fixed one of these parameters from the known resonant branching fractions of $D_{(s)} \rightarrow \phi(\rightarrow \mu^+ \mu^-)P$, while the remaining parameter is an unknown CP even strong phase δ_ϕ . The Breit-Wigner shape contains an additional phase that depends on the dilepton invariant mass. The hadronic dynamics of the short distance part of the amplitude is contained in a tensor form factor, f_T , that can be related to F_1 and F_0 form factors using the heavy quark symmetry. The shapes of the latter two form factors were determined on the lattice.

The interference term between the resonant and the short distance amplitude that drives the direct CP asymmetry depends decisively on the particular value of the strong phase. Namely, for large strong phase δ_ϕ , i.e., close to either $+\pi/2$ or $-\pi/2$, the CP asymmetry would vanish if the experimental bin enclosed the ϕ peak symmetrically. Conversely, the same asymmetry would be most sensitive to direct CP when the strong phase was either around 0 or π . In order to cover experimentally the whole range of strong phase values we have devised two asymmetries that are maximally sensitive either to peak-symmetric or peak-antisymmetric CP violation. Taking 0.008 for the imaginary part of C_7 , the two asymmetries can take values of the order 10 % for $\delta_\phi = \pm\pi/2$ or of the order 0.1 – 1 % for $\delta_\phi = 0, \pi$. When we multiply the asymmetries by the partial branching fractions in the corresponding bins, the two asymmetries provide almost even sensitivity for all values of the strong phase. For the $D \rightarrow \pi^+ \mu^+ \mu^-$ thus defined sensitivity amounts to $\sim 1.5 \times 10^{-9}$ and $\sim 4.5 \times 10^{-10}$ for $D_s \rightarrow K^+ \mu^+ \mu^-$. We conclude that measurements of partial width CP asymmetries in decays $D^+ \rightarrow \pi^+ \mu^+ \mu^-$ and $D_s^+ \rightarrow K^+ \mu^+ \mu^-$ might be useful in investigating whether new physics in chromomagnetic operator is responsible for direct CP violation in singly Cabibbo suppressed decays to two pseudoscalar mesons.

ACKNOWLEDGMENTS

N. K. thanks Benoît Viaud for discussions about the experimental sensitivity in charm semileptonic decays. We thank D. Bečirević for comments on the form factors and resonant amplitudes. This work is supported in part by the Slovenian Research Agency. N. K. acknowledges support by *Agence Nationale de la Recherche*, contract LfV-CPV-LHC ANR-NT09-508531.

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